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Energy Procedia 54 (2014) 569 – 579

Energy Procedia

4th International Conference on Advances in Energy Research 2013, ICAER 2013

Experimental Investigation on Performance and Emission Characteristics of a Diesel Engine Fuelled with Mahua Biodiesel Using Additive

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Abstract

The present paper investigates about the production of biodiesel from neat Mahua oil via base catalyzed transesterification and mixing of the biodiesel with a suitable additive (Dimethyl carbonate) in varying volume proportions in order to prepare a number of test fuels for engine application. The prepared test fuels are used in single cylinder water cooled diesel engine at various load conditions to evaluate the performance and emission parameters of the engine. The results of investigation show increase in brake power and brake thermal efficiency with load for all prepared test fuels. It is also noticed that brake thermal efficiency increases with the percentage of additive in all the test fuels. The brake specific fuel consumption decreases with increase in additive percentage. Exhaust gas temperature increases almost linearly with load for all test fuels and decreases with increase in additive percentage. It is also seen from the results that both CO and HC emissions tend to decrease with increase in additive percentage in biodiesel. The smoke and NOx emissions also decrease with increase in additive percentage in the biodiesel fuel. During the course of this experimental investigation it was found that the overall performance and emission characteristics of the engine was satisfactory with all the test fuels and improved with repeated experiments. All the test results significantly improved with increase in the additive percentage in biodiesel. Therefore the present paper provides a strong platform to continue further investigation on using biodiesel fuel in a diesel engine with variety of fuel additives under varying engine operating parameters.

Selection and peer-review under responsibility of Organizing Committee of ICAER 2013

*Keywords:*Mahua oil, Biodiesel, Additive, Performance, Emission

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Selection and peer-review under responsibility of Organizing Committee of ICAER 2013
doi:10.1016/j.egypro.2014.07.298

Nomenclature

CO	Carbon monoxide
HC	Hydrocarbon
NOx	Oxides of nitrogen
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
EGT	Exhaust gas temperature
^0C	Degree Celsius
DI	Direct injection
KOH	Potassium hydroxide
CO_2	Carbon dioxide
NO	Nitrogen oxide
BP	Brake power
FFA	Free fatty acid
B100	Pure biodiesel
B95	95% biodiesel + 5% additive
B90	90% biodiesel + 10% additive
B85	85% biodiesel + 15% additive
KW	Kilo watt
rpm	Revolutions per minute
Cc	Cubic centimetre

1. Introduction

Dueto excess use of the petroleum based fuels for industry and automobile application in present time, the world is facing severe problems like global energy crisis, environmental pollution and global warming. Therefore global consciousness has started to grow to prevent the fuel crisis by developing alternative fuel sources for engine application. Many research programs are going on to replace diesel fuel with a suitable alternative fuel like biodiesel. Non-edible sources like Mahua oil, Karanja oil, Neem oil, Jatropha oil, Simarouba oil etc. are being investigated for biodiesel production. Fatty acids like stearic, palmitic, oleic, linoleic and linolenic acid are commonly found in non-edible oils [1]. Vegetable oils blended with diesel in various proportions has been experimentally tested by a number of researchers in several countries. In developing countries like India, it is easily possible to grow these non-edible vegetable oils but not economically feasible to convert them to methyl esters undergoing different types of chemical process [2, 3]. Therefore, preheated oils blended with diesel are used and tested as alternative fuels in engines. In many literatures it was clearly mentioned that members in state government of India have declared that there is lots of scope for cultivating non-edible plants in different states of the country [4-6]. SrinivasRao et al. had carried out his experiments on non-edible oil which can substitute the present fossil diesel in the diesel engines. From their experimentation on an AVI type Kirloskar DI diesel engine with Karanja, Neem, Rice bran and Jatropha oil. It was concluded that brake thermal efficiency is lower for non-edible oil [7]. Bhanodaya Reddy et al. investigated on the use of PongamiaPinnata as alternate fuel to fossil diesel. During experimentation, they observed that engine runs smooth at 50% blend while 20% blend shows better performance and low emission characteristics than that of fossil diesel [8]. Basavaraj et al. during their experimentation observed that brake thermal efficiency is slightly inferior to that of fossil diesel with Honge oil and brake specific fuel consumption is less for B20 in comparison to other blends [9]. Demirbas had a thorough review on the production of biodiesel, its physical characteristics and different experimentation carried out in that area. He reviewed that Transesterification of triglyceride with methanol and ethanol are the most common methods that are being carried out during experimentation. He also stated that by Transesterification method, conversion yield can be raised up to 96% [10]. Karmee and Chala during their experimentation produced methyl ester from Pongamia oil by Transesterification of the raw oil with methanol and KOH where he got the conversion of 92% at 60 ^0C [11]. Burnwall and Sharma investigated and finally concluded that non-edible oil can also be used as alternate fuel in present diesel engine without any kind of modification, just by improving the properties of the fuel through base catalyzed Transesterification with alcohol to obtain mono-alkyl ester and super critical process to obtain the biodiesel [12]. Dorado et al. had carried out his experimentation on a four stroke diesel engine using olive oil methyl ester, where he observed that there is decrease in BSFC, 58% decrease in CO, 8.9% in CO2, 37.5% in NO and 32% reduction NOx in comparison to that of diesel [13]. Puhan et al. conducted their experiments on a four stroke diesel engine using Mahua oil methyl ester and observed that there is an increase in BSFC, BTE. While visualizing the emission part, there is a reduction of around 63% in HC, 70% in smoke opacity, marginable reduction on NOx and CO but slight increase in CO2 than that of diesel [14]. Altin et al. carried out the experiment on a direct injection diesel engine fuelled with sunflower oil, cotton seed oil, soyabean oil, refined corn oil and rape seed methyl esters. During the experimentation it was observed that there was loss of power, high particulate emission, and reduction in NOx for non-edible oils when compared with fossil diesel [15]. Bhatt et al. had investigated on Mahua oil methyl ester as a substitute fuel for fossil diesel in the present diesel engine with much modification and observed that 20% Mahua biodiesel can be used easily in diesel engine without any difference in BP, BSFC and power output. He also stated that performance can also be improved by increasing the compression ratio from 16:1 to 20:1 [16]. Wang et al. during his experimentation using non-edible oil in a diesel engine observed that EGT is higher at high loads, marginable changes in CO and NOx in comparison to that of fossil diesel [17]. This paper describes the findings of experiments conducted on a diesel engine to investigate about its performance and emission parameters with a number of test fuels prepared from Mahua biodiesel and an additive (Dimethyl carbonate). The purpose of using an additive in blended form with biodiesel is to enhance the combustion and lower the engine exhaust emissions.

1.1. Transesterification

There are four different ways through which non-edible oils can be converted into methyl esters are transesterification, blending, emulsion and pyrolysis out of which transesterification is the most commonly used method [18,19]. Transesterification is a chemical reaction that occurs between triglyceride and alcohol in presence of catalyst to obtain methyl ester and glycerol as by product. Transesterification mainly depends upon the amount of alcohol and catalyst, pressure, time, FFA and amount of water. Oils with large amount of free fatty acid are difficult to pass through the conversion process because it will form soap solution in presence of the catalyst. This further prevents separation of methyl ester from glycerol [20]. Sashikant et al. stated that raw Mahua oil contains FFA of about (20-25)% and therefore conversion of the oil into biodiesel is necessary [21].Acid catalyzed transesterification is most commonly used process because it is a reversible reaction. In the transesterification process methanol and ethanol are more common. Methanol is more extensively used due to its low cost and physiochemical advantages with triglycerides and alkali are dissolved in it [22]. Studies have been carried out on different oils like Soyabean, Sunflower, Jathropa, Karanja, Neem etc. Mostly biodiesel is produced by base catalyzed transesterification process of vegetable oil and it is more economical. Here the process is a reaction of triglyceride with alcohol to form mono alkyl ester commonly known as biodiesel and glycerol as by product. The main reason for doing titration to biodiesel is to find out the amount alkaline needed to completely neutralize any free fatty acid present, thus ensuring a complete transesterification [3].

The chemical reaction which describes the preparation of biodiesel is:

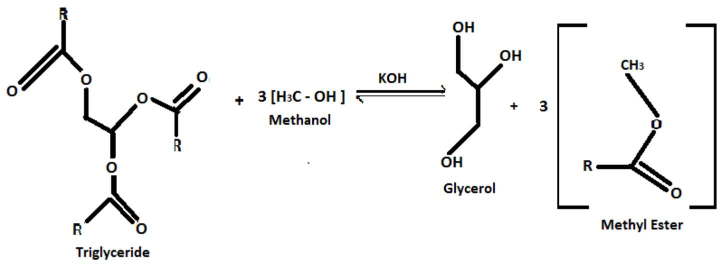

Fig. 1. Reaction process for transesterification.

2. Materials and methods

2.1. Mahua (MadhucaIndica) oil

Raw Mahua oil is generally collected from the kernel of Mahua tree. It is basically a medium size tree found in different parts of India. It is available in most of the rural areas in India. Mahua tree is a deciduous tree which grows to a height of 60-70 feet and has a life span of 7-20 years and fruits till 55 years. Each of these trees produces approximately around 20-40 kg of seeds per year. The average Mahua oil yield per annum is 1, 35,000 million tons in India. The raw oil is greenish yellow in colour. FFA composition of the Mahua oil is shown in the Table 1. Generally the raw oil contains 36mg/gms acid value with 18% FFA which is more than 1%. Therefore, it is necessary to pass the oil through base catalyzed transesterification process to reduce the acid value below (1-2) mg/gems [23].

Table 1. Composition of Free Fatty acid present in Mahua (MadhucaIndica) oil.

Fatty acid	Structure	Formula	Weight
Palmitic	16.0	$C_{16}H_{32}O_2$	23.1
Stearic	18.0	$C_{18}H_{36}O_2$	21.6
Arachidic	20.0	$C_{20}H_{40}O_2$	1.8
Oleic	18.1	$C_{18}H_{34}O_2$	38.2
Linoleic	18.2	$C_{18}H_{32}O_2$	11.3

2.2. Dimethyl Carbonate

Di methyl carbonate is a colourless, transparent liquid under normal temperature. Some important properties of it are given in Table 2.

Table 2.Properties of Dimethyl Carbonate.

Molecular Formula	$C_3H_6O_3$
Molar mass	90.08 gm/mole
Appearence	Clear liquid
Density	1.069-1.073 gm/mole
Melting point	(275-277) K

2.3. Methodology

One liter of neat Mahua oil is heated in an open beaker to a temperature of 100-110 ^{0}C to remove water particles present in oil followed by filtration of oil. The oil is processed under base catalyzed transesterification method where it is mixed with 200 ml of methanol and 6.5 gms of sodium hydroxide pellets in a round bottom flask on a hot plate magnetic stirring arrangement for 1-1.5 hours up to 60 ^{0}C and then it is allowed to settle down for about6-8 hours to obtain biodiesel and glycerol. The biodiesel obtained in the process is further washed with distilled water for 2- 3 times for removal of acids and heated above 100^{0}C to separate the moisture present in the biodiesel. Hence pure Mahua biodiesel is obtained.

2.4. Preparation of test fuel blends

Various test fuel blends were prepared by blending Mahua biodiesel with additive in various volume proportions. In the present work B85, B90, B95, B100 and the diesel fuel are used as the test fuels where B85 represent 85% biodiesel and 15% additive. Similarly B90 and B95 represent 90% biodiesel with 10% additive and 95% biodiesel with 5% additive respectively. B100 represents pure biodiesel without additive.

3. Experimentation

3.1. The Test Engine

Fig. 2. Photograph of the test engine.

3.2. Experimental procedure

The experimental study was carried out to investigate the performance and emission characteristics of a direct injection diesel engine with Mahua oil methyl ester using additive and comparing it with that of diesel. The prepared biodiesel was passed through various tests to determine its physical and chemical properties like kinematic viscosity, specific gravity, flash point, fire point, cloud point, pour point, ash content, calorific value etc... Ash content was carried out by taking 10ml of fuel in a cubicle which is then heated to about (500-600) ^{0}C for 2 hours. After heating the cubicle the left out part inside it is nothing but ash which is then weighed to calculate the amount of ash content. Cloud point and pour point apparatus is used to measure the cloud and pour point of biodiesel and the data collected is compared with that of diesel. After the test is over, Mahua oil methyl ester was blended with additive in various proportions like B95, B90, B85, etc…where B95 indicates 95% biodiesel and 5% additive. The engine opted for the experimentation is having a wide range of application in agricultural sector. Technical specification of diesel engine is elaborated in Table 2. The diesel engine was first initially started with diesel and then with the prepared test fuels. Speed of the engine was kept constant at 1500 rpm under varying load conditions to measure the performance parameters such as brake power, brake thermal efficiency, brake specific fuel consumption and exhaust gas temperature and also to measure the emission parameters like carbon monoxide, smoke opacity, unburnt hydrocarbon and nitrogen oxide emissions for both diesel and the prepared test fuels with the help of multi gas analyzer.

Table 3. Test Engine Specification

Particulars	Description
Engine type	Four stroke, single cylinder, vertical water cooled, diesel engine
Bore diameter	80 mm
Stroke length	110 mm

Compression ratio	16.5:1
Rated power	3.67 KW
Rated speed	1500 rpm
Dynamometer	Eddy current type

3.3. Experimental procedure

Table 4. Comparison of fuel properties for diesel and Mahua biodiesel

Properties of fuels	Unit	Diesel	Mahua biodiesel
Kinematic viscosity at 40 ^{0}C	cSt.	4.57	5.39
Specific gravity at 15^{0}C	-	0.8668	0.8712
Flash point	^{0}C	42	157
Fire point	^{0}C	68	183
Pour point	^{0}C	-18	2
Cloud point	^{0}C	-3	16
Cetane index	-	50.6	51.2
Calorific value	KJ/Kg-K	42850	42293

4. Result and Discussion

4.1. Brake thermal efficiency (BTE)

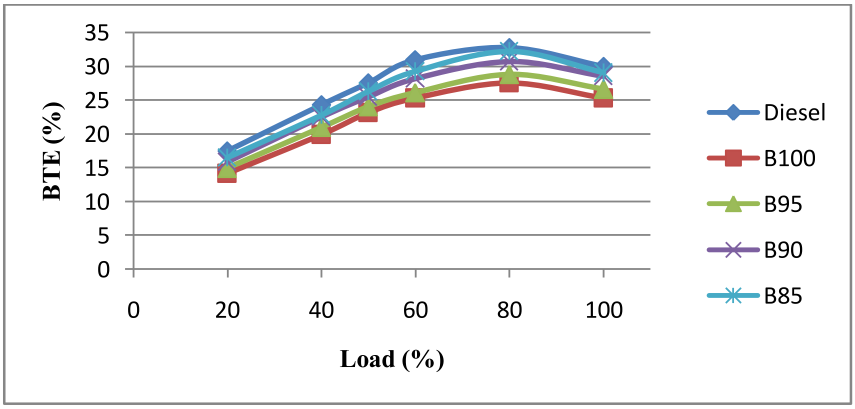

Fig. 3.Variation in brake thermal efficiency with load.

Fig. 3shows the variation in brake thermal efficiency in case of diesel, B100, B95, B90 and B85. It is clearly seen that BTE increases with increase in load up to 80% and then decreases at full load due to incomplete combustion. From the present test results it is observed that diesel has highest brake thermal efficiency than that of other test fuels which is because of its higher heat content, lower viscosity, lower density and higher volatility in comparison to Mahua biodiesel [24]. However, increasing the percent of additive with biodiesel the BTE increases with respect to load and shows very close behaviour to that of diesel because of increase in heat content, reduction in viscosity, density and increase in volatility which leads to better combustion of the test fuels [25-27]. The BTE obtained at full load for diesel, B100, B95, B90 and B85 are 30.09%, 26.63%, 28.01%, 29.74% and 29.97% respectively.

4.2. Brake specific fuel consumption (BSFC)

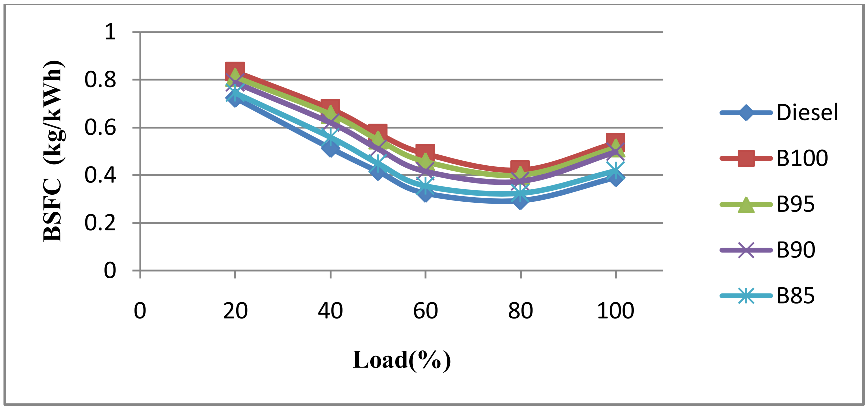

Fig. 4.Variation in brake specific fuel consumption with load.

Fig. 4 shows the variation in BSFC for diesel, B100, B95, B90 and B85. It is observed that BSFC first decreases for all the test fuels with increase in load i.e. up to 80% and then tends to increase with increase in load. It is seen that BSFC is highest for pure biodiesel and lowest for diesel because of high viscosity, density, low volatility and low heat content of pure biodiesel when compared with that of diesel [28, 29]. However, increasing the additivepercentagein biodiesel, BSFC decreases with respect to load and shows close results to that of diesel. This may be due to improved combustion, low viscosity, high volatility of the test fuels using additive [25, 26]. Different values of BSFC for diesel, B100, B95, B90 and B85 are 0.387, 0.556, 0.503, 0.4993 and 0.4104 Kg /Kwh respectively.

4.3. Exhaust gas temperature (EGT)

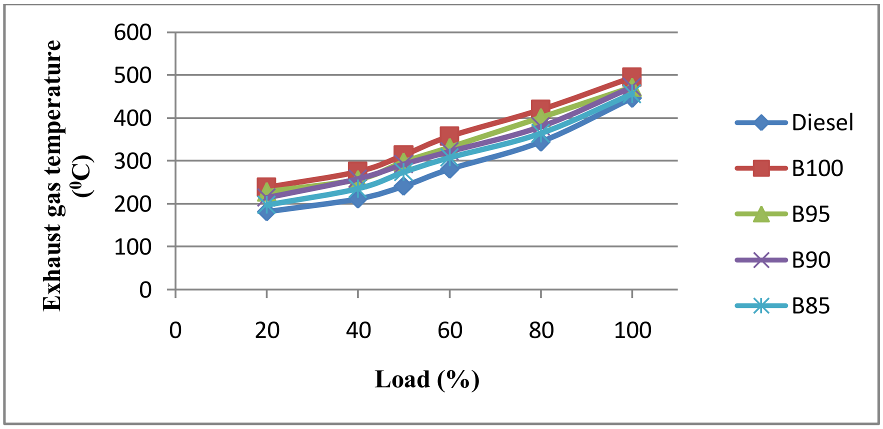

Fig. 5.Variation in exhaust gas temperature with load.

Fig. 5 shows variation of EGT with respect to load for different test fuels. It is observed that EGT increases with increase in load for all test fuels and diesel. It can also be seen from the graph that diesel exhibit low EGT when compared with other test fuels. Biodiesel exhibit highest EGT at all loads due to high combustion temperature of biodiesel because of higher oxygen content [24]. It is also visualized that with increase in percent of additive EGT decreases. The EGT obtained for diesel, B100, B95, B90 and B85 are 439 ^{0}C, 489 ^{0}C, 467 ^{0}C, 454 ^{0}C and 451 ^{0}C respectively.

4.4. Carbon monoxide (CO)

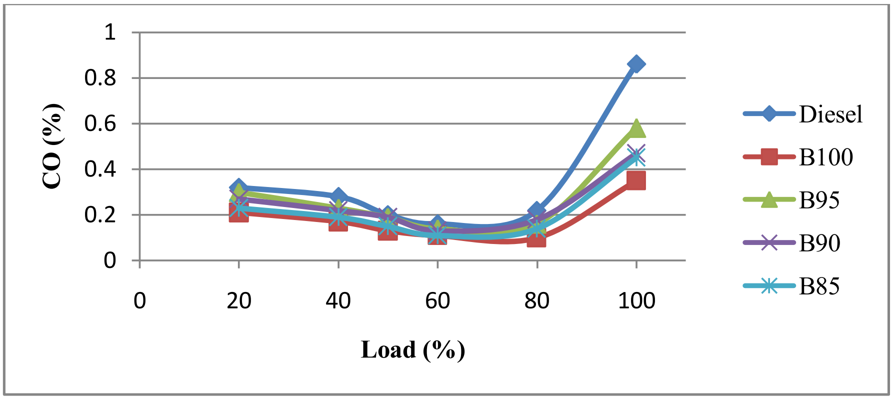

Fig. 6.Variation in CO emission with load

Fig. 6 shows the variation in CO emission with respect to variation in load. It is observed that CO emission initially decreases at lower loads Up to 70% and then increases sharply for all the prepared test fuels. CO emission is highest for pure biodiesel because of poor spray characterization that results in improper combustion which gives rise to CO formation [24, 30]. However, with increase in additive percentage CO decreases for all the prepared test fuels because of good spray characterization, good air-fuel ratio and proper combustion. Maximum CO emission for diesel, B100, B95, B90 and B85 are 0.887%, 0.383%, 0.573%, 0.507% and 0.486% respectively.

4.5. Hydrocarbon (HC)

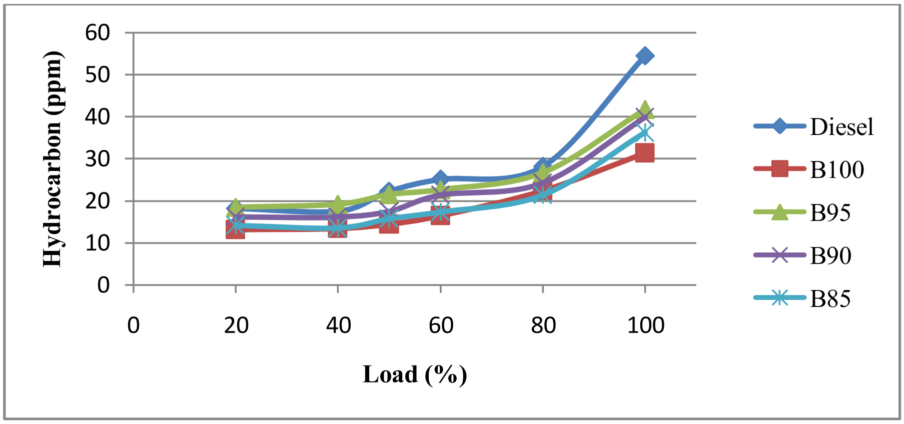

Fig. 7. Variation in HC emission with load

Variation in HC emission at different load conditions for diesel, Mahua biodiesel and Mahua biodiesel with varying additive percentages are shown in fig. 7. It is seen that unburnt hydrocarbon emission increases with that of load for all prepared test fuels. From fig. 7 it is understood that biodiesel produces less HC emission in comparison to that of diesel because of better combustion of the test fuel and its blend with additive due to presence of oxygen [31, 32]. However, with increase in percentage of additive HC emission increases with respect to load because of low cylinder pressure and temperature causing a comparatively lower burning rate. HC emission for diesel, B100, B95, B90 and B85 at full load condition are obtained as 55.67 ppm, 31.093 ppm, 41.22 ppm, 39,87 ppm and 34.63 ppm respectively.

4.6. Smoke opacity

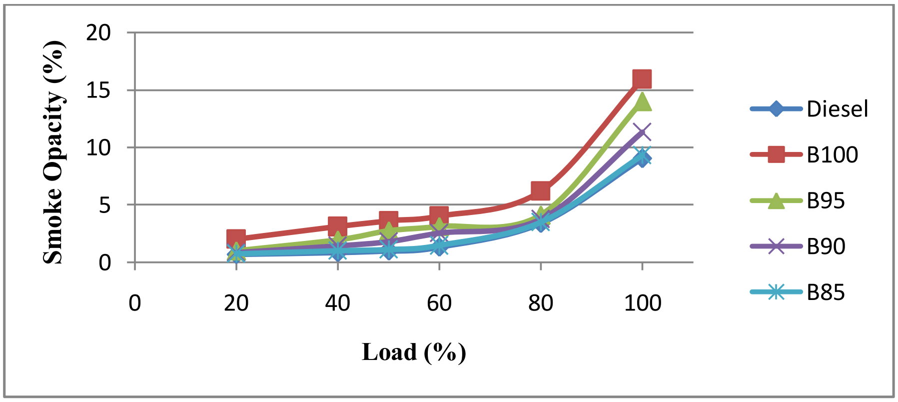

Fig. 8. Variation in smoke emission with load

Variation in smoke emission with respect to load is shown in fig. 8. It is observed that smoke emission increases with increase in load Up to 80% and then increases sharply. It is highest for pure biodiesel because of high viscosity, low volatility, high density, low heat content and heavy molecular structure in comparison to that of diesel which may cause incomplete combustion because of lack of oxygen at highest load [28]. However, with increase in percentage of additive, smoke emission decreases and attains similar trend as that of diesel. This may be due to reduced viscosity, increased volatility and decrease in density of the biodiesel causing proper combustion. The smoke emission obtained at full load for diesel, B100, B95, B90 and B85 are 8.7%, 17.04%, 14.43%, 12.09% and 8.81% respectively.

4.7. Oxides of nitrogen (NO_x)

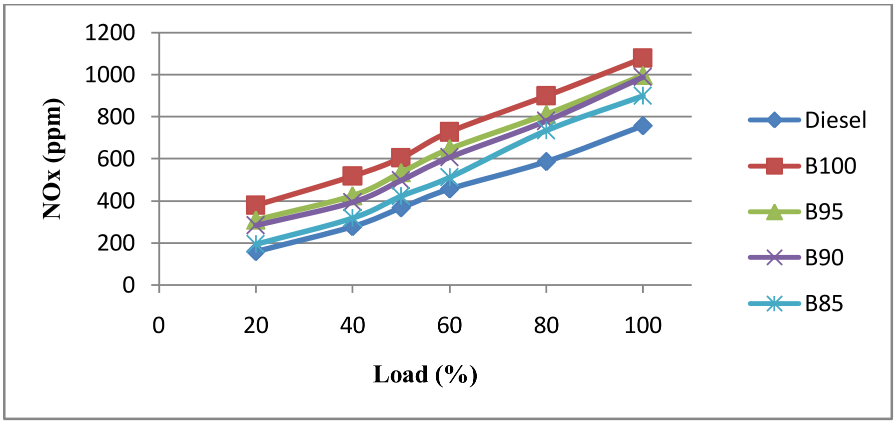

Fig. 9. Variation in NOx emission with load

Fig. 9 exhibits the variation in NOx emission with load for diesel, B100, B95, B90 and B85. From the literature it is revealed that NOx is directly proportional to power output of the engine because NOx emission increases with increase in combustion and exhaust temperature[33]. The present test results show that NOx emission increasesalmost linearly with increase in engine load which is because of higher cylinder pressure and temperature at higher loads [28, 29, 33]. It is found highest for pure biodiesel because of high oxygen content which results in complete combustion causing high combustion temperature. Results also reveal that NOx decreases with higher additive percentage because of reduction in engine in-cylinder temperature because of smooth combustion, causing reduction in EGT [25, 26]. At highest load NOx emission for diesel, B100, B95, B90 and B85 are found to be 573ppm, 1059ppm, 988ppm, 967ppm and 836ppm respectively.

5. Conclusion

During the present investigation several tests were carried out on a four stroke single cylinder vertical water cooled direct injection diesel engine using diesel, Mahua biodiesel and Mahua biodiesel with additives at different volume proportions. From the experimentation following conclusions were drawn.

- Brake thermal efficiency increases with increase in additive percentage in Mahua biodiesel and it is lower in case of pure biodiesel.
- Brake specific fuel consumption is highest for pure biodiesel at all loads because of high density, high volatility and low heat content of biodiesel but with increase in percentage of additive, BSFC decreases because of better combustion.
- Exhaust gas temperature is found highest for pure biodiesel. This may be due to high combustion temperature of biodiesel because of high oxygen content. It is seen that EGT decreases with increase in additive percent in biodiesel.
- CO and HC emissions are highest for diesel and lowest for pure biodiesel because of higher oxygen content. It is also concluded that with increase in additive percentage in Mahua oil methyl ester both CO and HC tends to decrease.
- Smoke and NO_x emissions are found highest for pure biodiesel because of high viscosity, high volatility and low heat content as compared to that of diesel. It is seen that both smoke and NO_x emissions decrease with increase in percentage of additive to the Mahua biodiesel.

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